AWARD NUMBER: W81XWH-11-2-0058

TITLE: Improved Training Method for Rapid Rehabilitation of Amputees

PRINCIPAL INVESTIGATOR: Kenton R. Kaufman, PhD, PE

CONTRACTING ORGANIZATION: Mayo Clinic
Rochester, MN 55905

REPORT DATE: May 2015

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;
Distribution Unlimited

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*



| 1. REPORT DATE | 2. REPORT TYPE | 3. DATES COVERED |
|---|---|---|
| May 2015 | Final | 1Mar2011 - 28Feb2015 |

**4. TITLE AND SUBTITLE**

**Improved Training Method for Rapid Rehabilitation of Amputees**

**5a. CONTRACT NUMBER** W81XWH-11-2-0058
**5b. GRANT NUMBER**
**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**
Kenton R. Kaufman, PhD, PE

E-Mail: Kaufman.kenton@mayo.edu

**5d. PROJECT NUMBER**
**5e. TASK NUMBER**
**5f. WORK UNIT NUMBER**

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**
Mayo Clinic
Charlton North L-110L
200 First Street SW
Rochester, MN 55905

**8. PERFORMING ORGANIZATION REPORT NUMBER**

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

**10. SPONSOR/MONITOR'S ACRONYM(S)**

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION / AVAILABILITY STATEMENT**

Approved for Public Release; Distribution Unlimited

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**
The U.S. military is providing state-of-the-art prosthetic devices to warfighters with amputations so that they may more easily adapt to the different surfaces and environments they are face in the free-living environment. In addition to walking and changing direction, amputee patients must be able to manage uneven terrain, crowded environments, stairs, ramps, and hills. ***The largest problem for a person with lower extremity amputation is falls***. Even with the newer technologies, falls and injuries due to falling are still an issue. Falling history and decreased balance confidence are associated with reduced mobility capability and social activity. ***The goal of this research effort was to rehabilitate individuals with lower extremity amputations to reduce falls using a novel training method.***

We enrolled 25 research subjects with unilateral transtibial or transfemoral amputation at the Naval Medical Center San Diego. The training was a secondary rehabilitation program, implemented after conventional rehabilitation. The training utilized a microprocessor-controlled treadmill designed to deliver task-specific training perturbations. The program consisted of six, 30 minute sessions delivered over a 2-week period. Trunk motion and velocity were assessed using a perturbation test in an immersive virtual environment, since trunk kinematics have been shown to determine fall likelihood. Twenty subjects completed the training. Mean trunk flexion angle and velocity significantly improved after participating in the training program. The Gait Quality Index (a combined measured of temporal spatial, kinematic, and kinetic measurements of gait) also demonstrated improvement. The improved performance was maintained up to 6 months. Subjects reported decreased uncontrolled and semi-controlled falls in their free-living environment outside of the research laboratory. ***These results indicate that task-specific training is an effective rehabilitation method to reduce falls in warfighters with lower limb amputations.***

**15. SUBJECT TERMS**
Rehabilitation, Amputee Limb Loss, Lower Extremity Prosthesis, Stability, Falls

| 16. SECURITY CLASSIFICATION OF: U | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| | | | | | USAMRMC |
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | 19b. TELEPHONE NUMBER *(include area code)* |
| Unclassified | Unclassified | Unclassified | UU | 16 | |

**Standard Form 298 (Rev. 8-98)**
**Prescribed by ANSI Std. Z39.18**

## Table of Contents

## Introduction

The US global war on terrorism has resulted in many US warfighters sustaining extremity injuries. The US military is currently providing state-of-the-art prosthetic devices to patients with amputations. While amputee patients may try to focus on the advanced technology to try to solve some of the adjustment issues, "high tech" does not always equate to "high function". In addition to walking and changing direction on a variety of surfaces, amputee patients must be able to manage uneven terrain, crowded environments, stairs, ramps, and hills. The key factor that limits the ability of persons with lower limb amputations to achieve maximum functional capabilities is falls. Among individuals with a lower extremity amputation, 52% reported having fallen in the previous 12 months, 49% reported being fearful of falling, and 65% had low balance confidence scores. Falls by warfighters with a lower extremity amputation can have serious consequences, including loss of confidence, developing fear of falling, and injury. As a result, those individuals with limited balance and mobility are at risk for diminished quality of life. The goal of this research effort was to rehabilitate warfighters with a lower extremity amputation to increase trust in their prosthesis and reduce falls by using a novel training method. Deliverables included a quantitatively derived, deployment ready, advanced gait rehabilitation system and method that could improve functional outcome and/or shorten the time required for injured service men and women to return to active duty or to a productive civilian life.

**Keywords**
Rehabilitation, Amputee Limb Loss, Lower Extremity Prosthesis, Stability, Falls

## Overall Project Summary

This report describes a four year research effort to develop and test a novel training technique aimed at increasing and/or accelerating the functional capabilities of warfighters with a lower extremity amputation and enhancing their return to active duty or a productive civilian life.

25 subjects (19 transtibial and 6 transfemoral) were enrolled (Figure 1). Subject functional capabilities were collected at four time points. Subjects were tested before starting the training protocol to establish their baseline capabilities. The subsequent training consisted of 6 training sessions over a 2-week timeframe. The subjects were tested again following completion of the training. To evaluate the extent to which the training was retained, all subjects were assessed for functional outcomes at 3 and 6 month time points following completion of the training.

We experienced some compliance issues with the study. Of the 20 subjects who completed the training, six subjects did not complete the 3-month post training assessment. One subject moved after completing the training and did not return for follow-up. Three subjects failed to respond to communications and two subjects developed medical issues. Five subjects completed the training but not the final 6-month post training assessment. Two subjects moved, two subjects failed to respond to communications, and one subject developed medical issues. Two subjects failed to respond for their 3-month study but returned for their 6-month study. *Importantly, none of the dropouts were due to the training program.*

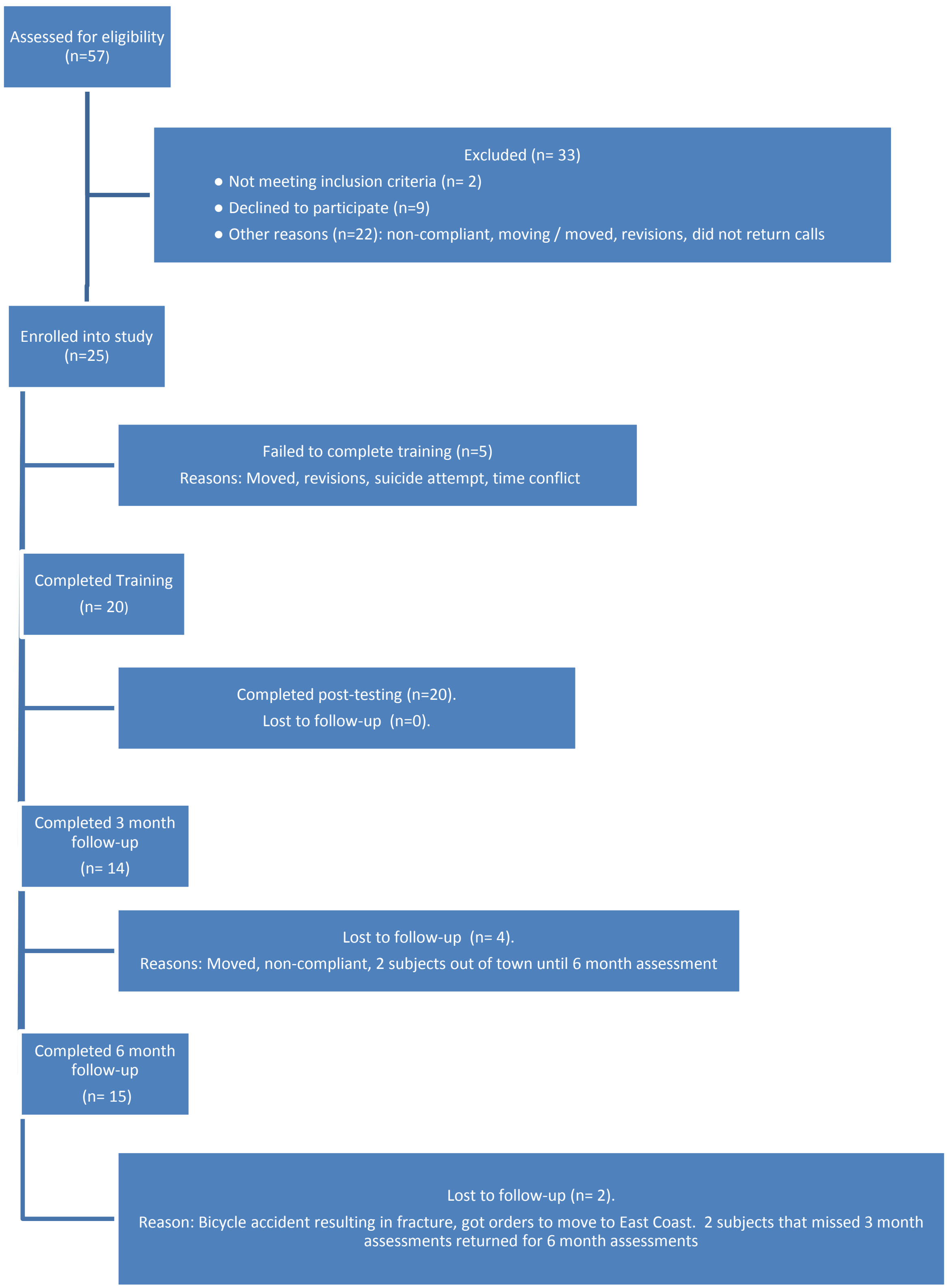


**Figure 1**. Subject flow through study.

The fall prevention training program utilized an Active-Step treadmill (Simbex, Lebanon, NH). This microprocessor-controlled treadmill was designed to deliver large task specific training perturbations that simulated a trip. There were six, 30 minute training sessions conducted over a

2-week period. During each training session, the task difficulty was increased as the patient's motor ability progressed. Three types of perturbations were delivered to subjects during each training session. Two "static" and one "dynamic" perturbations were used: (1) *static step*: the belt moved while the patient was standing still and the patient responded with one forward step; 2) *static walk*: the belt moved while the patient was standing still and the patient responded with multiple forward steps: and 3) *eTRIP*: while the subject walked on the treadmill the perturbation was delivered at a random time and the subject responded with multiple forward steps (i.e. continue walking).

Assessment of the training program effectiveness was done using a perturbation testing protocol in a Computer Assisted Rehabilitation Environment (CAREN, Motek Medical BV, Amsterdam). This fully immersive virtual environment comprises a 6 degree-of-freedom motion platform containing an instrumented dual belt treadmill with integrated force plates. The platform is surrounded by a 180 degree screen. During the testing protocol large perturbations simulating a trip in the natural environment were delivered. The limb that was on the ground (stance limb) during the treadmill perturbation is described as the perturbed limb in this paper. Six perturbations (3 left limb/3 right limb) were delivered in a randomized manner while the subject walked for five to six minutes. The walking speed for each subject was controlled for leg length by normalizing to a Froude number (FR) of 0.2, where FR = $v^2/gl$, v is the walking speed, g is the gravitational constant, and l is the leg length (1). This test assessment of the rehabilitation program was performed before and after the two week training on the Activestep treadmill. The key outcome variables were peak trunk flexion and trunk velocity between time of treadmill perturbation and recovery step completion. These variables have been shown to determine the likelihood of a fall (2, 3).

Patient centered information was also collected prior to and at the conclusion of the training. The Prosthesis Evaluation Questionnaire (PEQ-A) was used to quantify patient satisfaction. For the PEQ-A, an uncontrolled fall was defined as a sudden loss of balance without any time to protect against a fall. A semi-controlled fall was defined as a loss of balance with awareness that a fall was occurring so that there was the opportunity to brace for the fall or catch something avoid injury and land in a protected fashion.

The results of the study are divided into three categories.

*I. Functional Improvements following Training*

The functional performance improvements of the subjects with amputations were assessed in three ways: Lab assessments, a Standardized perturbation test, and Fractal analysis of the stepping patterns.

<u>Lab Assessments</u>: The training program has been beneficial and resulted in improvements of the perturbation-induced peak trunk flexion angle and trunk flexion velocity for conditions during which the prosthetic and non-prosthetic limbs were "tripped" when they were in single limb support. For subjects with a *transtibial amputation* (Figure 2), peak trunk flexion angle, when the prosthetic limb was tripped, improved from pre-training (mean value of 30 degrees; 95% CI, 23-37) to after training (22 degrees; 95% CI, 18-25; $p<0.001$). Likewise, peak trunk flexion velocity improved from pre-training (124 degrees/sec; 95% CI, 94-154) to after training 82 deg/sec; 95% CI, 71-92; $p<0.004$). The results displayed a significant side-to-side difference for peak trunk flexion angle ($p=0.01$), with perturbations of the non-prosthetic limb resulting in higher peak angles. Prosthetic limb trips also exhibited significantly greater peak trunk flexion velocity compared with trips of the non-prosthetic limb ($p=0.005$). For subjects with a *transfemoral amputation* (Figure 3), the trunk flexion angle, when the prosthetic limb was tripped, improved from pre-training (28

degrees; 95% CI, 9-48) to after training (19 degrees; 95% CI, 8-30; p=0.048). Likewise, the trunk flexion velocity improved from pre-training (109 degrees/sec; 95% CI, 52-166) to after training 99 deg/sec; 95% CI, 60-138; p=0.17). The results displayed a significant side-to-side difference for peak trunk flexion angle (p=0.0002), with trips of the non-prosthetic limb resulting in higher peak angles. Non-prosthetic limb trips also exhibited significantly greater peak trunk flexion velocity compared with trips of the prosthetic limb (p=0.0002).

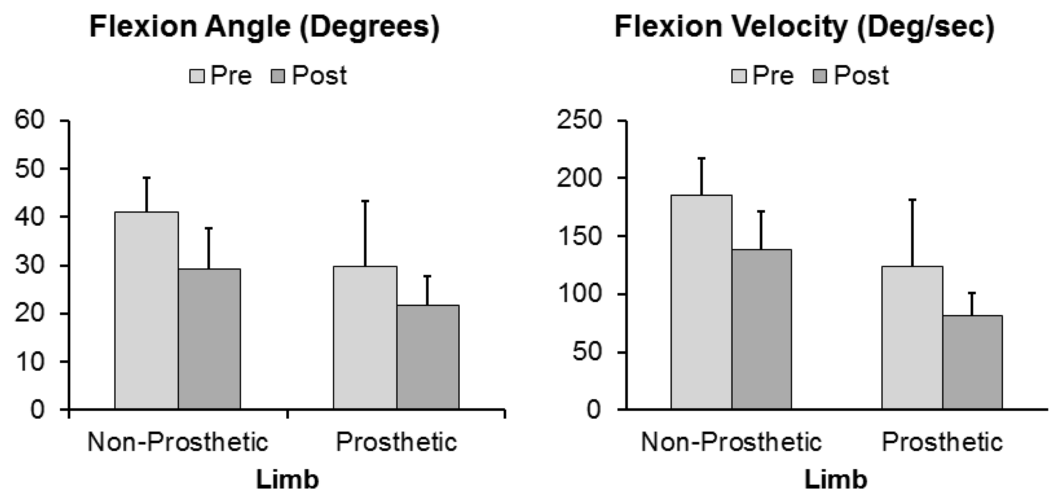


**Figure 2**: Mean trunk flexion angle (degrees) and velocity (deg/sec) before (Pre) and after (Post) training when the subjects with *transtibial amputations* were subjected to trips of the prosthetic and non-prosthetic limb. There were statistically significant changes in trunk kinematics. Trips of the prosthetic limb resulted in significantly greater changes. The data demonstrated a clinically significant improvement in ability to recover from a large postural perturbation simulating a trip and avoid falling.

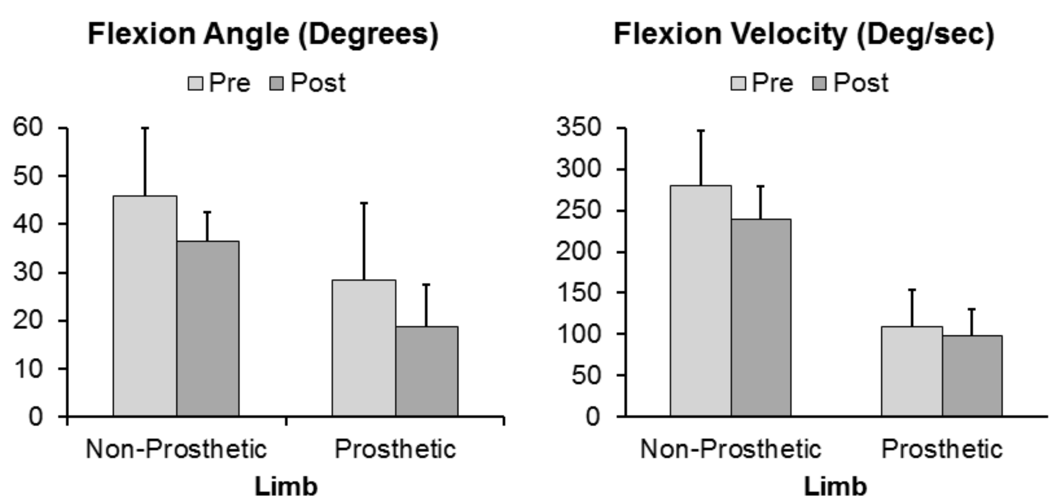


**Figure 3**: Trunk flexion angle (degrees) and velocity (deg/sec) before and after training when the subjects with *transfemoral amputations* were subjected to trips of the prosthetic and non-prosthetic limb. There were statistically significant changes in trunk flexion angle. Trips of the prosthetic limb resulted in significantly greater changes. The data demonstrated a clinically significant improvement in ability to recover from a large postural perturbation simulating a trip and avoid falling.

Standard Perturbation Test: Before beginning the training program, a standard perturbation was administered without instructing the subject which leg to use to avoid falling. The subject was considered to have passed the standard perturbation if he recovered without assistance from the safety harness. The subject was considered to have failed if he irrecoverably lost his balance and the harness prevented a fall.

Examining the results of subjects with a *transtibial amputation*, in the pretest condition, only 1 of 15 subjects (7%) passed and 7 of the 14 subjects (50%) who fell elected to attempt recovery on the prosthetic limb. Following training, the standard perturbation was administered again. After the two week training protocol, 13 of the 15 subjects (87%) passed the standard perturbation and 8 of the 13 subjects (62%) chose to use the *prosthetic* limb as their recovery step to avoid falling. These results demonstrate improved ability to recover from a large perturbation simulating a trip as well as increased reliance on the prosthetic limb.

Looking at the subjects with a *transfemoral amputation*, in the pretest condition, only 1 of 5 subjects (20%) passed and all subjects (100%) who fell elected to attempt recovery using the non-prosthetic limb. Following training, the standard perturbation was administered again. After the two week training protocol, all subjects (100%) passed the standard perturbation and all subjects (100%) chose to use the *non-prosthetic* limb as their recovery step to avoid falling. These results demonstrate improved ability to recover from a large perturbation simulating a trip, though they were still more comfortable using their sound limb to recover – a probable indicator of the inability of the prosthesis to respond fast enough during a fall.

Fractal Analysis of Foot Placement During Treadmill Locomotion: We conducted a secondary analysis to establish if the fractal-like 1/f properties of step width during treadmill walking by patients with transtibial amputations varies from that of non-amputee control subjects. This type of analyses helps to determine the presence or absence of synergies by which the central nervous system stabilizes the performance variable ("variance"). The absence of a synergy occurs when the value of the bad variance, that which has a deleterious effect on the performance variable, exceeds that of the good variance. We expected that compared to control subjects the patients with amputations would demonstrate significantly wider step width and significantly higher step width variability (measured as the standard deviation of step width). We also expected that compared to control subjects the amputees would demonstrate 1/f properties of step width that trended toward uncorrelated white noise. Fourteen male military service members with traumatic unilateral transtibial amputations and a control group of 12 male non-amputee military service members, walked for 10 minutes in the Computer Assisted Rehabilitation Environment (CAREN, Motek Medical BV, Amsterdam). The step width time series for the 10 minute walking trial was calculated from the trajectories of the markers located on the heels that had been collected using a 14 camera motion capture system operating at 60 Hz (Motion Analysis Corp, Santa Rosa, CA USA).

Three dependent variables were extracted from the step width time series, the average step width and its standard deviation (step width variability), and a variable, β, representative of the randomness of the time series (Figure 4). β was computed by first converting the step width time-amplitude series to a frequency-amplitude power spectrum that was then log transformed. The resulting data were fit using linear regression. The regression coefficient from the regression, β, was used as the index of signal randomness. As β approaches zero the signal approaches the characteristics of white noise. In contrast, as β approaches 1.0 the signal approaches the characteristics of pink noise, reflective of activity of multiple interacting control systems acting over different temporal and/or spatial scales.

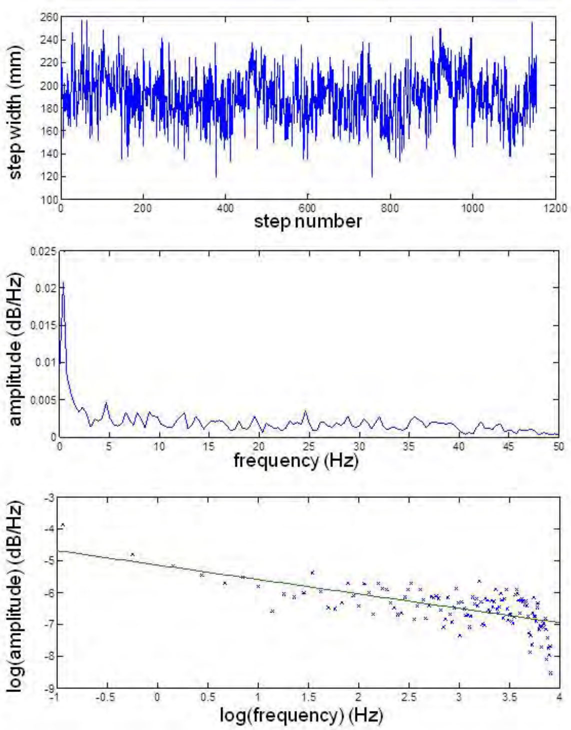


**Figure 4**: (Top panel) Time series of step width (n=1124) of a non-amputee subject. (Middle panel) Power spectrum of step width time series. (Bottom panel) Log-transform of power spectrum data with the linear regression line, the slope of which, β is interpreted to reflect the extent to which randomness is present in the original time series.

Contrary to expectations, the step width of the amputee subjects (135±36 cm) was not significantly larger than that of the control subjects (147±31 cm; $p>0.05$). Indeed, the step width of the control subjects was about nine percent larger than that of the subjects with amputations. Consistent with expectation, the step width variability of the amputee subjects was significantly larger (34±7 cm) than that of the control subjects (28±7 cm; $p=0.022$). Because the absence of a significant effect for step width does not mean that the values are similar, we elected to represent step width variability as the coefficient of variation (i.e., sd/mean). For the control and amputee groups the coefficients of variation for step width variability were 0.27±0.10 and 0.20±0.07, the between-group difference was significant ($p=0.035$). Contrary to expectations the between-group difference for β was not significant; -0.52±0.14 and -0.51±.0.16 for the amputee and control subjects respectively ($p=0.79$).

The results indicated that the step width time series of the amputee subjects was more variable than that of the control subjects but not more complex. Based on our previous work we expected that the step width time series of the control subjects would have been associated with β ranging between -0.85 and -1.0. This has been the range for our work with young healthy subjects during conditions that included normal treadmill walking, narrow base of support treadmill walking and treadmill walking while performing an attention-demanding task. The largest contributor to this outcome may be the between-site differences in the testing environment, specifically the design, dimensions and features of the treadmill. The width of the CAREN treadmill is almost twice that of the previously used treadmill. It is also possible that the larger presence of randomness may reflect more entrainment of gait dynamics on the CAREN treadmill. However, it is not clear why, or even if, treadmill dimensions would modify this effect in a frontal plane gait variable. Additional work will be necessary to confirm this surprising and potentially clinically important finding in a separate group of subjects.

The importance of this work reflects the widespread use of treadmills during clinical and scientific studies of human locomotion. There are numerous practical issues that may need to be considered for between-site sharing and comparison of data if between-site differences in treadmill designs are found to significantly influence gait variables in the medial-lateral plane.

It is premature to discard or accept the potential clinical value of β with regard to step width time series. Similar measures for sagittal plane step kinematics are demonstrably sensitive to clinical conditions that affect gait and balance and seem to be associated with falls. Ultimately, the clinical value of β with regard to step width time series will be defined by the extent to which it is affected by the variations specific to environment in which the primary data are collected as well as the relationship that may be demonstrated between β collected in these clinical/laboratory environments and that which occurs during community-based ambulation.

*II. Ability of the training method to achieve rapid rehabilitation of patients with amputations*

In this study, a new metric was developed to define the deviation of each subject from the average gait of a healthy control population. The new metric is called the Gait Quality Index (GQI). It is a measure of the number of standard deviations the subject differs from the control population. A reduction in the GQI indicates an improvement in gait. The GQI evaluated the temporal-spatial, kinematic, and kinetic aspects of gait and represented relevant aspects of these measures into one value. The GQI is an average of three sub-scores: the Temporal Spatial Quality Index (TsQI), composed of seven variables: velocity, cadence, step length (right and left), stride length (right and left), and step width; the Kinematic Quality Index (KmQI), composed of eight kinematic variables: the sagittal and frontal plane measures of the trunk (lateral tilt, forward flexion), pelvis (obliquity, tilt), and hip (flexion/extension, ab/adduction), along with the sagittal (flexion/extension) plane measures of the knee and ankle (dorsi/plantarflexion) normalized to the gait cycle; and the Kinetic Quality Index (KnQI), which consists of the hip moments in the frontal and sagittal plane, and knee and ankle moments in the sagittal plane normalized the gait cycle.

The GQI was used to evaluate if there were any differences in gait before and after training. The GQI was calculated from subjects' gait data while walking in the NMCSD gait lab. Results demonstrated that the GQI was reduced following training for both subjects with an above-knee (AK) or below-knee (BK) amputation (Figure 5). This reduction indicated an improvement in gait. The most improvement was observed in the kinematics (KmQI) and kinetics (KnQI) parameters. The gait of the subjects with a BKA was consistently better than for subjects with an AKA.

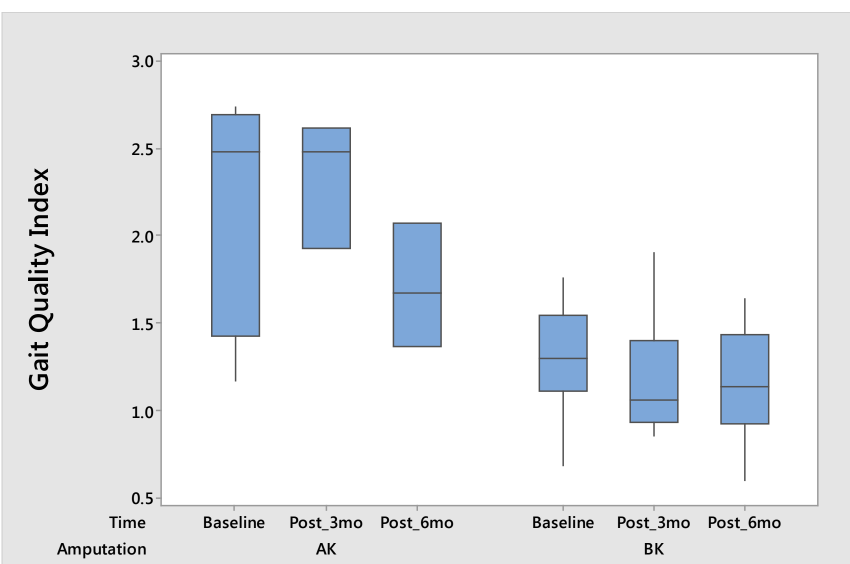


**Figure 5**. Changes in the Gait Quality Index (GQI) over time for subjects with an above-knee (AK) or below-knee (BK) amputation. The GQI was calculated before (baseline) and 3 months and 6 months after training. A lower GQI indicates an improved gait. The central line represents the median, the edges of the box are the 25th and 75th percentiles, and the whiskers the lowest datum still within 1.5 IQR of the lower quartile, and the highest datum within 1.5 IQR of the upper quartile.

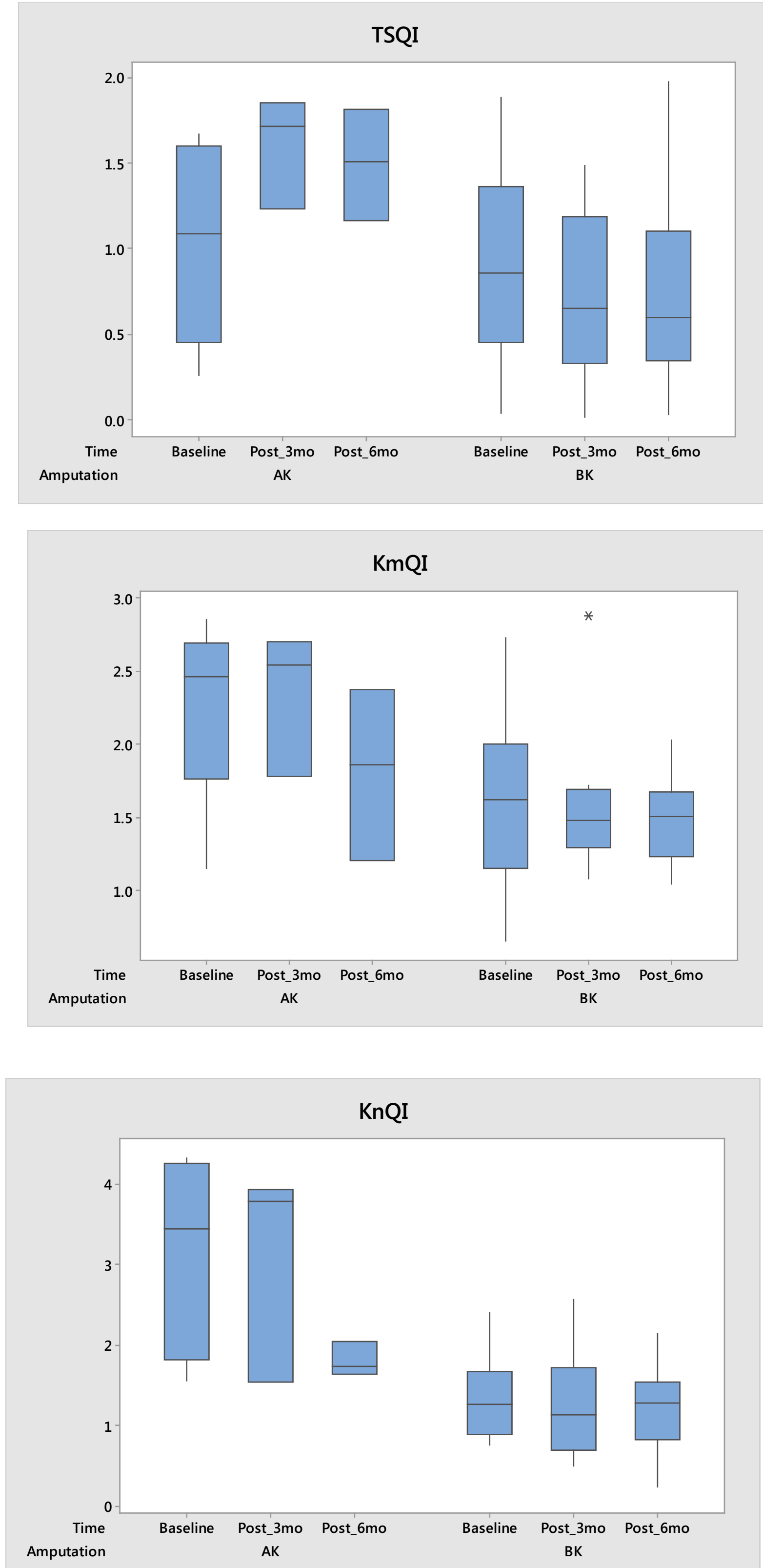


**Figure 6.** Changes in the sub-scores of the Gait Quality Index (GQI) over time for subjects with an above-knee (AK) or below-knee (BK) amputation. The largest improvements occurred in the subjects with an above-knee amputation. These subjects improved both their gait kinematics and kinetics.

*III. Motor skill retention following completion of rehabilitation training*

The retention over time of the motor skill acquired during the training was assessed in the laboratory and in the free-living environment.

Lab assessments: Importantly, the motor skills acquired were retained at 3 and 6 months after completion of the training. For the subjects with a *transtibial amputation*, the peak trunk flexion angle when the non-prosthetic limb was tripped had a mean of 29 degs (95% CI, 25-35) at 0 months, a mean of 32 degrees (95% CI, 28-36) at 3 months, and a mean of 30 degrees (95% CI, 26-34) at 6 months. The peak trunk flexion velocity for the non-prosthetic limb had a mean of 139 degs/sec (95% CI, 121-157) at 0 months, a mean of 136 (95% CI, 119-152) at 3 months, and 129 degs/sec (95% CI, 112-146) at 6 months. The trunk flexion angle of the subjects when the prosthetic limb was tripped had a mean of 22 degs (95% CI, 18-25) at 0 month, 25 degs (95% CI, 19-31) at 3 months, and 24 degrees (95% CI, 20-29) at 6 months. Likewise, the trunk flexion velocity for the prosthetic limb was a mean of 82 degs/sec (95% CI, 71-92) at 0 months, 94 degs/sec (95% CI, 71-116) at 3 months, and 87 degs/sec (95% CI, 71-103) at six months. There were no significant changes in the peak trunk flexion angle ($p = 0.19$) or peak trunk flexion velocity ($p = 0.35$) over time after the training ended. The motor skill retention was present when either the prosthetic or non-prosthetic limb was tripped. There were side-to-side differences in the trunk flexion angle ($p = 0.04$) and trunk flexion velocity ($p=0.001$). Trips of the non-prosthetic side resulted in larger trunk flexion and higher trunk flexion velocities.

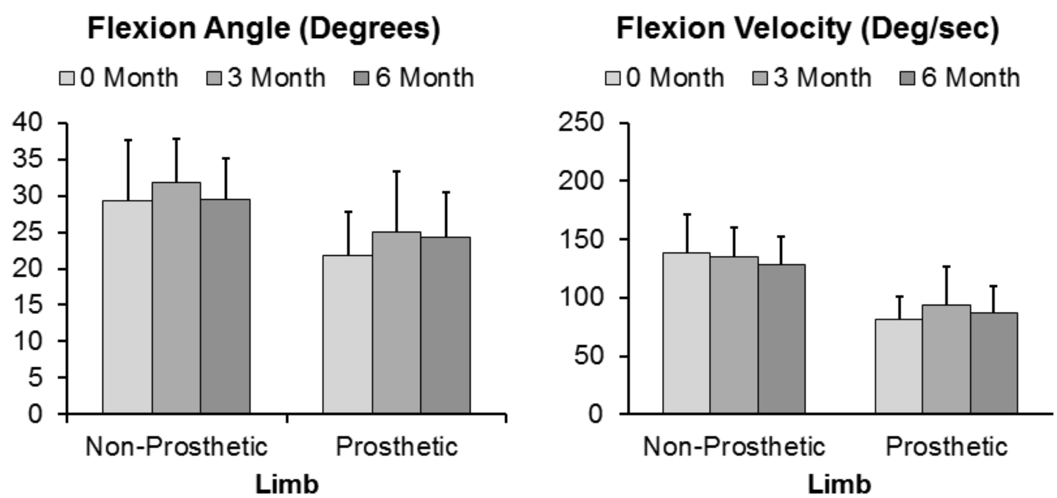


**Figure 7:** Mean trunk flexion angle (degrees) and velocity (deg/sec) over time following completion of the training for subjects with a *transtibial amputation*. There were no significant changes in trunk kinematics. Trips delivered to the non-prosthetic side resulted in significantly higher trunk flexion angles and velocities than when trips were delivered to the prosthetic side. The data demonstrates that the subjects retain the training effect up to six months after completing the training.

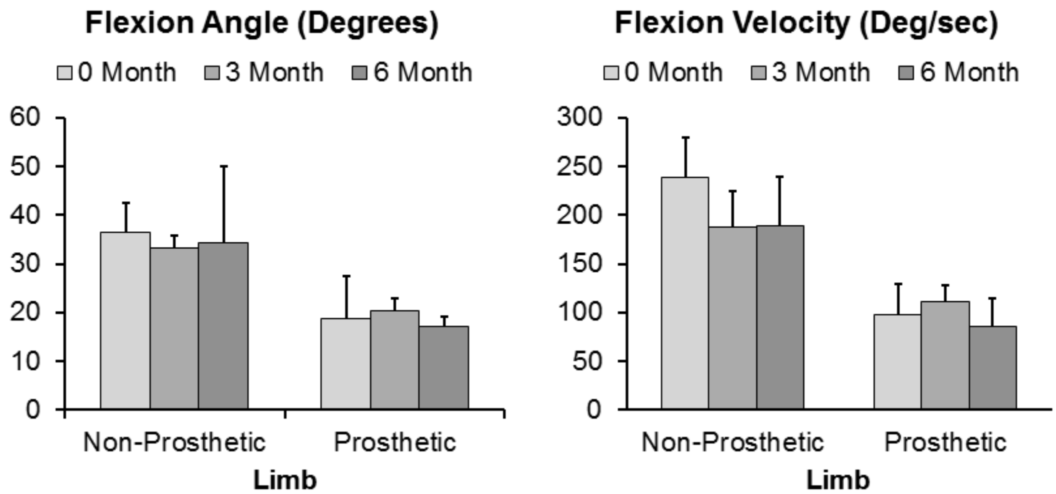


**Figure 8:** Trunk flexion angle (degrees) and velocity (deg/sec) over time following completion of the training for subjects with a *transfemoral amputation*. There were no significant changes in trunk kinematics. Trips delivered to the non-prosthetic side resulted in significantly higher trunk flexion angles and velocities than when tripswere delivered to the prosthetic side. The data demonstrates that the subjects are able to retain the training effect up to six months after completing the training.

For the subjects with a *transfemoral amputation*, the trunk flexion angle of the subjects when the prosthetic limb was tripped had a mean of 19 degs (95% CI, 8-30) at 0 month, 20 degs (insufficient data for 95% CI) at 3 months, and 17 degrees (95% CI, 13-22) at 6 months. Likewise, the trunk flexion velocity when the prosthetic limb was tripped was a mean of 99 degs/sec (95% CI, 60-138) at 0 months, 110 degs/sec (95% CI, insufficient data) at 3 months, and 86 degs/sec (95% CI, 15-157) at six months. The peak trunk flexion angle when the non-prosthetic limb was tripped had a mean of 36 degs (95% CI, 29-44) at 0 months, a mean of 33 degrees (95% CI, insufficient data) at 3 months, and a mean of 34 degrees (95% CI, -4 - 73) at 6 months. The peak trunk flexion velocity for when the non-prosthetic limb was tripped had a mean of 239 degs/sec (95% CI, 189-289) at 0 months, a mean of 188 (95% CI, insufficient data) at 3 months, and 189 degs/sec (95% CI, 63-314) at 6 months. There were no significant changes in the peak trunk flexion angle ($p = 0.34$) or peak trunk flexion velocity ($p = 0.06$) over time after the training ended. The motor skill retention was present when either the prosthetic or non-prosthetic limb was tripped. There were side-to-side differences in the trunk flexion angle ($p = 0.03$), but not in the trunk flexion velocity ($p=0.06$). Trips of the non-prosthetic side resulted in larger trunk flexion and higher trunk flexion velocities.

<u>Assessment in the free-living environment:</u> Patient-reported outcomes confirmed the success of the training program. Their responses indicated increased confidence in their ability to recover from the postural perturbations encountered in the community. Sixty percent of the subjects reported that the incidence of stumbles had decreased after the training program. Fifty percent of the subjects indicated that the number of semi-controlled falls had been reduced to zero after training. All subjects (100%) reported that the number of uncontrolled falls was zero after training. Reduction of stumbles and falls was maintained over time.

## Key Research Accomplishments

- 25 subjects enrolled
- 20 subjects trained
- Training is accomplished in six, 30 minute sessions conducted over a 2 week period
- Results demonstrates improvements in ability of individuals with unilateral lower extremity amputations to avoid a fall following large postural perturbations
- Military personnel undergoing the novel rehabilitation training are showing greater improvements in their gait over a shorter time-frame compared to an amputee control group.
- Critical training effects are retained for at least 6 months following completion of the training
- Patients with amputations report reduction in falls in their free-living environment
- Application was developed within the CAREN to create an objective assessment of ability to recover from a potential fall. This can be transferred to other military treatment facilities housing a CAREN.

## Conclusion

We have designed and developed a demonstrably effective, clinically relevant and scientifically based method for increasing and accelerating the progressive adaptation of warfighters with a lower extremity amputation to their prosthesis. The training is a secondary rehabilitation program, implemented after conventional rehabilitation. This rehabilitation method uses a novel treadmill and an innovative treadmill training protocol. The training method is aimed at increasing the ability for amputee patients to rely on their prostheses, particularly in a challenging environment, and thus, improve their functional capabilities. Based on the results, warfighters with unilateral amputations have reduced falls and retained their improved skills for at least six months following training.

In order to test the outcomes in a repeatable and reliable manner, we also developed a test protocol on the CAREN which allowed us to deliver large postural perturbations which resulted in falls by untrained subjects. This protocol has utility in assessing other interventions aimed at improving the gait and stability of warfighters with lower extremity amputations and other neural and musculoskeletal injuries.

Future work should expand this research program to warfighters with bilateral lower extremity amputations and service members with limb salvage procedures. The current program demonstrated efficacy in subjects with unilateral amputations. This enrollment criterion was used to validate the method on individuals who are not as mobility-challenged. Further, when the program was conceived, there was not the preponderance of patients with bilateral lower extremity amputations and patients with limb salvage procedures. Given the success of the current program, advancing the training to other warfighters is now warranted.

## Publications, Abstracts, and Presentations

- Peer-Reviewed Scientific Papers
  - Sessoms PH, Wyatt M, Grabiner M, Collins JD, Kingsbury T, Thesing N, Kaufman K. Method for evoking a trip-like response using a treadmill-based perturbation during locomotion. *Journal of Biomechanics*, 47(1):277-280, 2014.
  - Kaufman KR, Wyatt MP, Sessoms PH, Grabiner MD. “Task specific Fall Prevention Training is Effective for Warfighters with Transtibial Amputations”, *Clinical Orthopedics and Related Research*, 472:3076-3084, 2014.

  - Lugade V, Fortune E, Morrow M, Kaufman K. Validity of using tri-axial accelerometers to measure human movement – Part I: Posture and movement detection. *Medical Engineering & Physics*, 36:169-176, 2014 Feb. PMC3866210. PMID23899533.
  - Fortune E, Lugade V, Morrow M, Kaufman K. Validity of using tri-axial accelerometers to measure human movement – Part II: Step counts at a wide range of gait velocities. *Medical Engineering & Physics*, 36(6):659-669, 2014. PMC4030415. PMID24656871.
  - Fortune E, Lugade V, Kaufman K. Posture and Movement Classification: The comparison of tri-axial accelerometer numbers and anatomical placement. *Journal of Biomechanical Engineering*, 136(5): 051003, April 2014. PMC4023813. PMID24337255
  - Fortune E, Morrow MMB, Kaufman KR. Assessment of gait kinetics using tri-axial accelerometers. *Journal of Applied Biomechanics*. 30(5):668-674, 2014. PMCID: PMC4332389. PMID: 25010675

- Awards
  - Received **Best Poster Award** at the European Society of Movement Analysis for Adults and Children, Stockholm, Sweden, September 12-15, 2012

- Abstracts presented
  - Military Health System Research Symposium, Ft. Lauderdale, FL, August 6-9, 2012
  - European Society of Movement Analysis for Adults and Children, Stockholm, Sweden, September 12-15, 2012
  - American Physical Therapy Association, San Diego, CA, January 21-24, 2013.
  - International Society of Prosthetics and Orthotics, Hyderabad, India, February 4-7, 2013
  - Gait and Clinical Movement Analysis Society, Cincinnati, OH, May 14-17, 2013
  - International Society of Biomechanics, Natal, Brazil, August 4-9, 2013
  - Military Health System Research Symposium, Fort Lauderdale, FL, August 12-15, 2013
  - American Society of Biomechanics Meeting, Omaha, NE, September 4-7, 2013
  - O&P World Congress, September 18-21, 2013
  - Federal Advanced Amputation Skills Training Program, July 8, 2014
  - Military Health System Research Symposium, Fort Lauderdale, FL, August 18-21, 2014
  - American Society of Biomechanics, Columbus, Ohio, August 5-8, 2015
  - Military Health System Research Symposium, 2015
  - European Society for Movement Analysis in Adults and Children, Heidelberg, Germany, September 10-12, 2015

- Presentations During the Last Year
  - Kaufman K, Wyatt M, Sessoms P, Grabiner M. Fall Training Prevention for Warfighters with Lower Extremity Amputations, Military Health System Research Symposium, Fort Lauderdale, FL, August 18-21, 2014

## Reportable Outcomes

This project has resulted in several reportable outcomes. First we have developed a novel method of delivering computer-controlled disturbances to subjects walking on a treadmill in order to simulate trip responses. Second, we have designed and developed a demonstrably effective, clinically relevant, and scientifically based method for increasing and accelerating the progressive

adaptation of Warfighters with unilateral lower extremity amputation to their prostheses. This combined work has resulted in a quantitatively derived, advanced gait rehabilitation system and method that can improve functional outcomes of injured Warfighters. This will enable them to return to active duty or a productive civilian life.

## References


1. Alexander RM. Optimization and gaits in the locomotion of vertebrates. *Physiol Rev*. [Review]. 1989 Oct;69(4):1199-227.
2. Crenshaw JR, Kaufman KR, Grabiner MD. Trip recoveries of people with unilateral transfemoral and knee disarticulation amputations. *Gait and Posture*. 2013;38(3):534-6.
3. Owings TM, Pavol MJ, Grabiner MD. Mechanisms of failed recovery following postural perturbations on a motorized treadmill mimic those associated with an actual forward trip. *Clinical Biomechanics*. 2001;16:813-9.